EFFECT OF ADAPTATION TO LOWERED BAROMETRIC PRESSURE ON TOLERANCE OF HYPOCAPNIA

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ABSTRACT: Twenty-four subjects participated in the research, of which 12 were mountain climbers. The hypocapnic state was induced at normal barometric pressure by the method of voluntary hyperventilation. The EEG's, EKG's blood pressure and pCO_2 in alveolar air were recorded.

It was shown that mountain climbers are more tolerant of hypocapnia than those subjects who have not been conditioned to high altitude. Thus, in subjects of the control group, the average increase in frequency of heart contractions was 12% greater than in the mountain climbers. Stronger changes were observed on the EEG in comparison with mountain climbers in spite of the fact that in these latter the pCO_2 in alveolar air was reduced to lower values. No substantial difference was found in the reactions of the blood pressure.

These investigations showed that in the process of adaptation to high-altitude conditions the human organism reaches a higher tolerance of hypocapnia.

In the research conducted by Sirotinin, Vladimirov, Asyamolovaya and Malkin, as well as others, it was noted that the tolerance to hypoxic hypoxia in subjects adapted to high altitude is considerably higher than in unconditioned subjects [1, 3, 4].

Investigations of a group of mountain climbers showed that in the majority of them the increase in altitude tolerance was due basically to the considerable increase in pulmonary ventilation. In this respect, during the time that the mountain climbers remained at altitudes of 5000 - 7000 meters, they underwent a high saturation of arterial blood with oxygen and a lower partial pressure of CO_2 in the alveolar air as compared to the subjects of the control group.

There naturally arises the idea that during the period that they remain in the mountains in the process of conditioning man to oxygen starvation there is simultaneously developed an adaptation to hypocapnia which always accompanies hypoxic hypoxia. Here we may assume that in such subjects the increased tolerance to hypo-

capnia appears even under conditions of normal oxygen supply.

To explain this question we carried out investigations with 12 mountain climbers - master athletes age 26-40, who systematically /80 participated in high-altitude expeditions. As the control group we chose subjects who has passed the medical commission and who were permitted to make high-altitude ascents but who were not especially conditioned for a prolonged period of time under conditions of a rarefied atmosphere.

For creation of hypocapnia we used an arbitrary measured hyperventilation. For control of the amount of ventilation the subjects wore on their chests a rubber jacket which was filled with air. The rubber jacket was connected to a special pneumatic instrument of Moreyer capsule type, the recorder of which during inspiration and expiration was deflected to a strictly determined value as a function of the respirational volume. On the drum of the kymograph the paper was traced in such a way that the subject could follow the path of the pen and keep the frequency and depth of respiration established by the experimenter. The frequency of breathing was 30 per minute, the respirational volume was 2000-2200 cm^3, the volume of pulmonary ventilation 60-66 l per minute. The subjects were hyperventilated up to the appearance in them of the first "unusual" or even "unfavorable" sensations which were expressed in the form of paresthesia of different characteristics, vertigo, nausea or visual disorders. At the moment that such sensations appeared and then during the period of the distinct appearance on the EEG of slow oscillations, the intake of alveolar air with a subsequent determination in it of CO_2 (Holden apparatus) was measured.

Registration of the physiological functions was carried out on a 12-channel EEG from the firm "Saney". The recording from the EEG was accomplished bipolarly from the frontooccipital regions and monopolarly from the region of the sinciput, the temple, the occiput, both with open and with closed eyes. The EKG was simultaneously recorded in three standard leads; in several of the experiments the blood pressure was determined.

The data characterizing change in pCO_2 of the alveolar air, the pulse rate and the complaints of the subjects during the time of hyperventilation are shown in Table 1. As is obvious from the average time of hyperventilation prior to the appearance of unfavorable sensations in the group of mountain climbers was more prolonged (2 minutes, 20 seconds) than in subjects of the control group (1 minute, 40 seconds). In this case the average value of the alveolar pCO_2 for which the sensations in the mountain climbers occurred was 42.6 mm Hg, in the control group it was 24.5 mm Hg. The mean value in the increase of pulse rate during the time of hyperventilation in the control group was more significant (66%) than in the mountain climbers (54%) in spite of the higher degree of hypocapnia which was expressed in them.

In subjects of both groups in the process of hyperventilation the sensations occurred after different intervals of time and different values of the alveolar pCO_2. Thus in several of the mountain climbers the sensations appeared with a decrease in the alveolar pCO_2 to significant values (18.2, 19.2 mm Hg), whereas other /81
complaints appeared with a relatively high pCO_2 (26-27 mm Hg).

In the majority of mountain climbers the sensations appeared in the form of different types of paresthesia. The subjects of the control group in the majority of the investigations noted the beginning of vertigo or visual disorder and only at the end of hyperventilation did complaints appear of paresthesia.

To establish the physiological improvement which determined the characteristics of the course of the hypocapnic syndrome in the mountain climbers we attempted to compare the changes in the EKG and the EEG of the mountain climbers and in subjects of the control group.

As we know, the most constant symptom of hyperventilation is tachycardia. In our experiments during hyperventilation an increase in pulse rate was noted in all subjects. In this case no strict dependence was found between the degree of increase in pulse rate, changes in the EKG and the level of decrease in pCO_2 in alveolar air. Thus in three of the subjects with a relatively small degree of hypocapnia, 24-27 mm Hg, the pulse rate increased to 88-180% of the original values, whereas in others with a decrease in alveolar pCO_2 to 18-20 mm Hg, the pulse was increased only to 41-58%. In spite of this difference in the appearance of individual reactions, from the side of the cardiovascular system, to hypocapnia the average increase in frequency of cardiac contractions in the subjects of the control group was 12% greater than in the mountain climbers.

The overall direction of changes in the EKG in the subjects of both groups was characterized along with the sinusal tachycardia, increase in the wave voltage R_1 and T and an insignificant increase in the wave R_3. The time of the heart cycle decreased basically due to the decrease in the interval T-P, i.e., as a result of shortening the period of diastola in connection with which the value of the systolic characteristic determined according to Fogelson-Chernogorov increased.

The degree of decrease in the T waves as a rule depended on the original value; with higher T waves there was noted a more expressed flattening.

The described changes in the EKG during the time of hyperventilation were observed in the majority of subjects of the control group (9 subjects). In the group of mountain climbers these changes in the EKG were noted only in four experiments. In one of the mountain climbers the decrease in the waves P_1 and P_2, T_1

TABLE 1. ALVEOLAR pCO_2, PULSE RATE AND COMPLAINTS DURING MEASURED HYPERVENTILATION

No.	No. pCO_2, mm Hg		Time of Hyperventilation Before Onset of Adverse Sensations		Pulse at Moment of Onset of Adverse Sensations						Character of Sensations	
					Mountain Climbers			Control				
	Mountain Climbers	Control	Mountain-Climbers	Control,	Background	At Moment of Sensation	Increase,	Background	At Moment of Sensation	Increase,	Mountain Climbers	[illegible]
1	39,2—23,2	41,0—27,0	2'10"	1'14"	60	90	50	66	108	63	Heat	Vertigo
2	41,2—18,2	41,0—24,0	3'30"	1'45"	72	102	41	66	102	54	Paresthesis	Same
3	37,4—20,3	38,6—27,1	2'20"	50"	66	100	51	78	114	46	Vertigo	»
4	39,9—23,2	40,1—25,0	1'50"	2'00"	72	108	50	66	108	63	Paresthesis	Paresthesis
5	37,2—24,6	36,2—[illegible]	1'50"	2'20"	66	108	63	66	100	51	»	»
6	38,6—26,0	38,[illegible]	1'25"	1'30"	66	114	72	72	114	58	»	»
7	39,2—20,3	[illegible]	1'46"	1'15"	78	126	61	66	132	100	»	Vertigo
8	37,2—24,7	38,0—23,2	2'00"	2'10"	66	90	36	72	136	89	»	The Same
9	41,3—26,6	38,1—22,2	58"	2'35"	54	102	88	54	84	55	Light Vertigo and Paresthesis	Vertigo Heat
10	38,9—22,5	40,0—24,3	2'40"	2'30"	66	98	48	72	150	108	Paresthesis	Vertigo
11	40,1—19,2	38,2—32,3	3'40"	1'03"	72	114	58	78	108	38	Feeling of Inebriation	The Same
12	39,0—22,6	39,7—27,6	2'10"	48"	66	90	36	60	104	73	Paresthesis, Vertigo	Heat, Paresthesis
M	22,6	24,5	2'10"	1'40"			54			66		

and T_2 were associated with the phase of respiration. In inspiration the wave voltage decreased. In one case, hyperventilation produced a disruption in cardiac rhythm which was expressed in the appearance of individual ventricular extrasystoles.

In studying the recordings of blood pressure during the time of hyperventilation we were able to find certain dynamics in its change. Thus at the beginning of hyperventilation the blood pressure, both systolic and diastolic was decreased; then in proportion to the development of hypocapnia as a rule there appeared a diastolic pressure. The systolic pressure in one of the subjects increased insignificantly, reaching the original value, in others it remained, as before, at a slightly decreased level. No substantial difference in change in blood pressure during the time of hyperventilation between the mountain climbers and the subjects of the control group was noted.

Changes in the EEG during the time of hyperventilation have /83
been described by many authors who have widely used hyperventilation as functional test for the appearance of latent forms of epilepsy [2, 5, 6]. In the literature which is available to us we have found no indications where the authors, in describing the EEG during the time of hyperventilation, have taken the characteristics of the background EEG into account.

In subjects with a flat EEG (up to 20 mkv) the hyperventilation either produced an insignificant increase in amplitude of the biopotentials without visible changes in its frequency or was completely unaccompanied by changes in the bioelectric activity.

In the development of hyperventilation syndrome no strict dependence was established between the subjective sensations and the character of change in the bioelectric activity of the brain. At the moment that the sensations appeared in the subjects there was noted on the EEG different changes: the activation of α or β rhythm, the appearance of short groups of slow oscillations of increased amplitude. At the same time in several of the subjects even before the appearance of sensations on the EEG there was clearly observed the activation of δ and θ rhythms.

In comparing changes in the EEG at the time of hyperventilation in mountain climbers and subjects of the control group it was found that in the majority of mountain climbers (in 8) on the EEG at the moment of the appearance of unusual sensations there was noted an insignificant activation of the α rhythm or an increase in the high-frequency rhythms. In subjects of the control group the hyperventilation produced stronger changes in the EEG which were characterized by the appearance, in the majority of cases at the moment of the sensation, of individual or diffuse slow oscillations.

Thus the increased tolerance to hypocapnia in the majority of

mountain climbers on the ground in comparison with subjects of the control group indicates that in the process of adaptation to conditions of high altitude the human organism reaches an increased /84 tolerance of hypocapnia. It was quite extraordinary that the increased tolerance of hypocapnia appears not only the lowered barometric pressure under the conditions of oxygen deficiency but is also retained for a prolonged period of time after descent from the mountains. At the same time, in spite of the altitude conditioning, individual differences in the tolerance of hypocapnia are nevertheless retained. Certain subjects, probably those who are highly sensitive to CO_2 loss, in spite of the lengthy time which they spent at high altitudes do not substantially increase their tolerance of hypocapnia. On the basis of this research we can state as a working hypothesis the position that periodic conditioning to hypocapnia on the ground may increase the tolerance of man to the effect of hypoxic hypoxia.

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